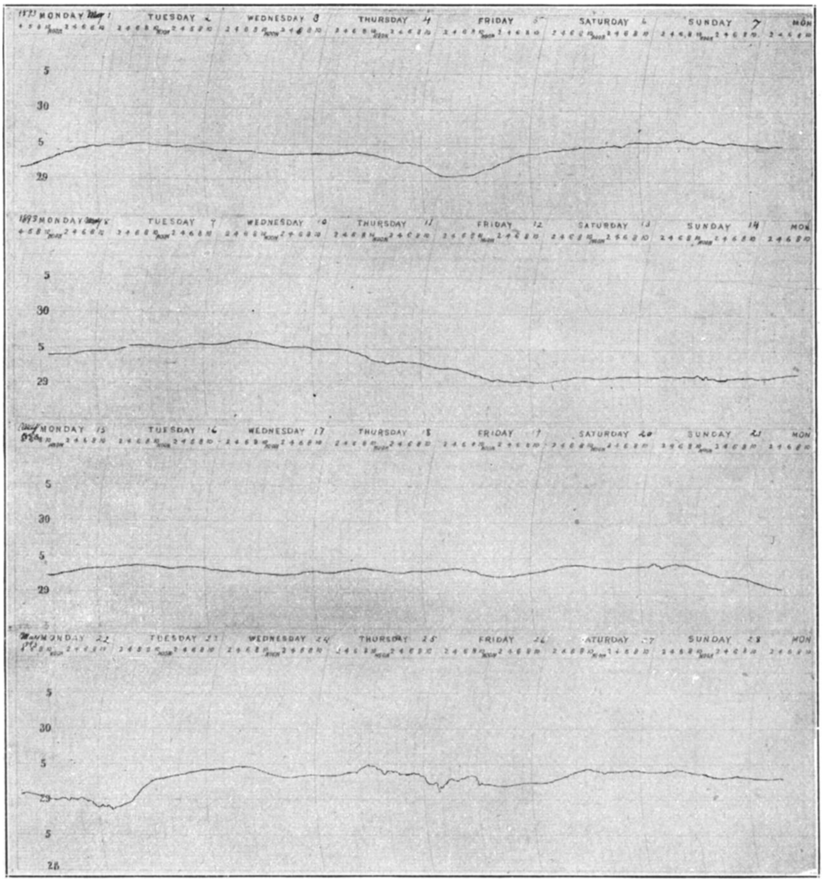
USE OF THE ANEROID BAROMETER IN GEOLOGICAL SURVEYING.

An attempt to unravel the geologic structure of any area should always be preceded by the establishment of a datum plane, and the reference of all points in the area to it, or in other words the geologic, should always be preceded by a topographic survey. This I take to be axiomatic, yet in practice such a preliminary survey is seldom made, except by the larger organizations, which are under state or national patronage, and not always even by these, because of the great expense involved, and because very few geologists are sufficiently familiar with the instruments and methods of the engineer to undertake such a work, and are not in a position to employ an engineer to do it for them. In reality however, results sufficiently accurate for practical purposes may be reached with an expenditure of time and money almost nominal, and by a method which should be mastered by every field geologist, whether he expects to make such surveys or not, on account of the use he can make of it in other directions. It is the object of this paper to set forth a method which I have used successfully for this purpose.

The aneroid barometer is essentially a metallic box having one or both ends formed by a thin elastic plate, which is usually corrugated to increase its elasticity, and the ends are often connected by a delicate spiral spring with the same object in view. If the air is partially exhausted from such a box, the elastic diaphragms will be forced slightly inward, and in this condition will respond to the least change in weight of the air. The small motion thus engendered is rendered visible by a system of three levers, the long arm of the last being connected by a chain with an axis carrying an index, which revolves in front of a graduated arc. The graduated circle is usually double, the inner arc indicating the weight of the air column in inches of mercury, while



BAROGRAM FOR MAY, 1893.

the outer shows corresponding differences of elevation in feet; for greater accuracy in reading, a vernier is usually attached. Instruments of this kind are to be had, which will plainly indicate differences of one or two feet in elevation. It is of course understood that these readings represent relative elevations only.

Equipped with an accurate land-survey map and an aneroid, the detailing of the topography of an area would be a simple matter, if it were not for the numerous sources of error which inhere in all barometers, but more especially in the aneroids. These sources of error may be classified as mechanical, observational, thermal, and atmospheric. They will be discussed in order, and the means of controlling them indicated.

Mechanical sources of error.—However perfect the mechanical construction of an aneroid may be, a slight shifting or cramping of its parts may give rise to an amount of friction which will prevent the registering of small changes in pressure, and when the change becomes sufficiently great to overcome the friction, the index will jump to its proper place. This difficulty may be overcome by gently tapping the face and side of the instrument before eaeh reading. It is to be borne in mind that while a gentle tap will release the mechanism, a more vigorous one is very liable to produce the error we are seeking to avoid.

Another mechanical source of error arises from slight changes which are continually taking place in the elasticity of the diaphragms. To avoid this the aneroid should be tested from time to time on known elevations, and the tension of the diaphragms regulated by a small screw at the back of the instrument, until the elevation is correctly given.

Errors in observation.—The weight of the levers is in part borne by the diaphragms, and must cause movement in them when the position of the instrument is shifted, hence all readings should be taken with the instrument in the same position, preferably with the dial horizontal. This is a matter of great importance, for the reading of a delicate instrument may be changed one hundred feet by simply reversing its position. If, however, the instrument is uniformly read from the same position, the

weight of the levers, etc., bearing on the diaphragms will always be the same, and so this source of error will be eliminated.

The index of a well-made aneroid should be exceedingly fine, flattened vertically, and should revolve as close as possible to the graduated arc, but even when both these conditions are fulfilled the reading may be varied as much as twenty feet by changing the line of sight, hence the instrument should always be held so that the line of sight will be perpendicular to the dial.

Errors due to changes in temperature.—All first-class instruments are supposed to be compensated for changes in temperature, but the compensation is never perfect. Each aneroid should be tested under varying temperatures, and the ratio of error noted. It will generally be found so small that it may be disregarded except in extreme cases, but if the ratio is large the instrument should be rejected.

Errors due to changes in atmospheric pressure.—The atmosphere is filled with eddies, formed by ascending and descending currents, which are called cyclones and anticyclones respectively. These eddies generally originate over the elevated plateaus of the cordilleran system, spread out until their diameter is measured by hundreds of miles, and move in an easterly direction across the continent, with an average velocity of twenty to thirty miles per hour.

In the eddies formed by ascending currents, or cyclones, as the air rises, it is replaced by surface currents which set in from all directions, with a spiral motion, toward the center. A careful study of an area marked "low" on the daily map issued by the National Weather Bureau will make this clear. As the cyclone moves toward some easterly point a wind from that direction tells of its approach, while a change in direction from east, through north or south, to some westerly point tells of its passage.

As soon as the particles of air come within the influence of the eddy, they are drawn upward, at first slowly, then more rapidly, until near the center they acquire the almost vertical motion of the vortex. This upward tendency of the air lessens

its apparent weight, and causes the barometer to fall. *A falling barometer indicates an approaching cyclone.* The fall continues until the trough, or line perpendicular to the direction in which the cyclone is moving, is reached, when it is changed to an upward movement.

This upward impulse of the air particles results in a loss of heat, and condensation of the contained moisture into visible drops, which are blown by the rapid currents of the upper atmosphere into long, wispy, hairy, cirrus clouds, which reach far beyond the cyclone's front. *Gradually thickening cirrus clouds herald a cyclone.* Behind the axis, the outflowing air has to contend against the general motion of the atmosphere, which is from west to east, and hence its velocity is much lessened. Any moisture condensed in this portion of the area will tend to form lumpy cumulus, rather than windy cirrus clouds. *Cumulus clouds mark the rear of the cyclone.*

The intensity of a cyclone, or the velocity of the ascending current, and consequently the rate at which the barometer rises or falls (barometric gradient) depends largely on the supply of moisture. If the amount of moisture carried into the area remains constant, the intensity of the cyclone, and the gradient, will be constant. If it increase, the intensity and gradient will increase, and if it diminishes, both will diminish, or if it fails, both will disappear. If the supply comes equally from all directions, the cyclone will remain nearly or quite stationary, but if the winds from one quarter bring more moisture than those from the others, the cyclone will move in that direction with a velocity governed by the supply. Changes in direction may produce as marked an effect on the gradient as changes in intensity, for they bring the observer into another part of the area. Many illustrations of change in gradient will be found in Plate I, which is the tracing of a self-registering barometer for the month of May, 1893.

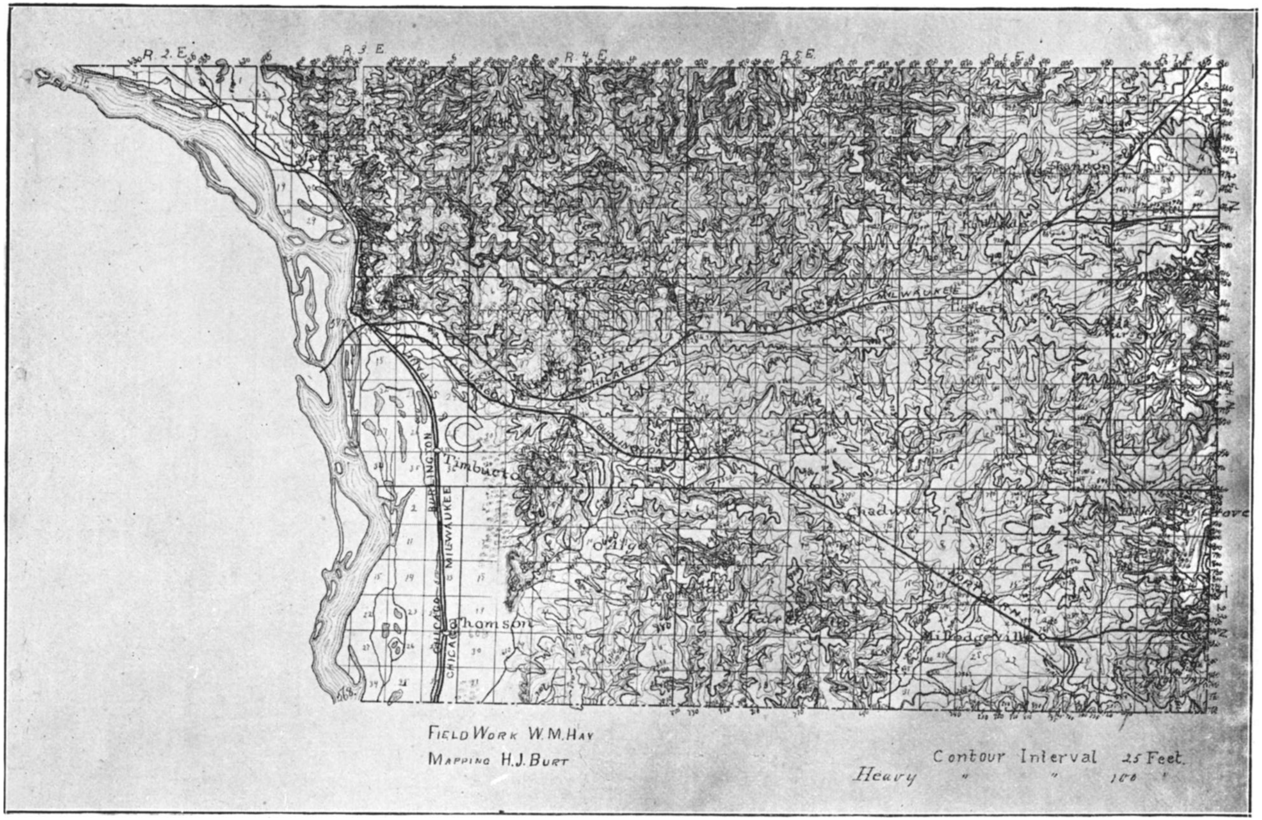
The characteristics of the cyclone which should be remembered in this connection are wind easterly in front, westerly in the rear; gradually thickening cirrus clouds in front, with cumulus

clouds in the rear; barometer falling in front, rising in the rear. It should also be remembered that a change in intensity or direction, may cause the barometer to fall in the cyclone's rear, or rise in its front, and that any change in direction or force of wind, or in character of cloud, is generally accompanied by a change in gradient.

In the descending eddy, or anticyclone, the conditions are just reversed. As the descending air nears the surface of the earth, it slides off horizontally, flowing away from the center in all directions, with a spiral movement; hence as the progressive motion of the anticyclone is from west to east—*a west wina must be its herald and an east wind mark its rear.* As the air from the colder upper regions settles toward the warmer earth there will be little tendency to form clouds, except those of the pure stratus type. In fact this is the only type of cloud which can occur in a typical anticyclone as defined above, but for reasons that will be explained further on, both cumulus and feathery cirrus clouds do occur in most anticyclonic areas. The downward motion of the air increases its apparent weight and so *the barometer rises in its front and falls in its rear.* Anticyclones are also subject to changes in intensity and direction similar to those which occur in cyclonic areas.

The characteristics of the anticyclone are: wind from some westerly point in front, becoming easterly in the rear; generally a clear sky, with perhaps a few cumulus clouds in front, and cirrus in the rear; rarely the whole sky becomes dull and leaden from the formation of pure stratus clouds; barometer rising in front, falling in the rear.

For our present purpose we may assume that the entire atmosphere is made up of such cyclonic and anticyclonic areas, in fact the assumption is not far from the truth in this latitude, and as each floats over us, it causes the index of our barometer to move upward or downward, the extremes covering an arc that represents nearly three thousand feet of elevation. From this it will be seen how fruitful a source of error these atmospheric configurations may be, and how essential it is for anyone who



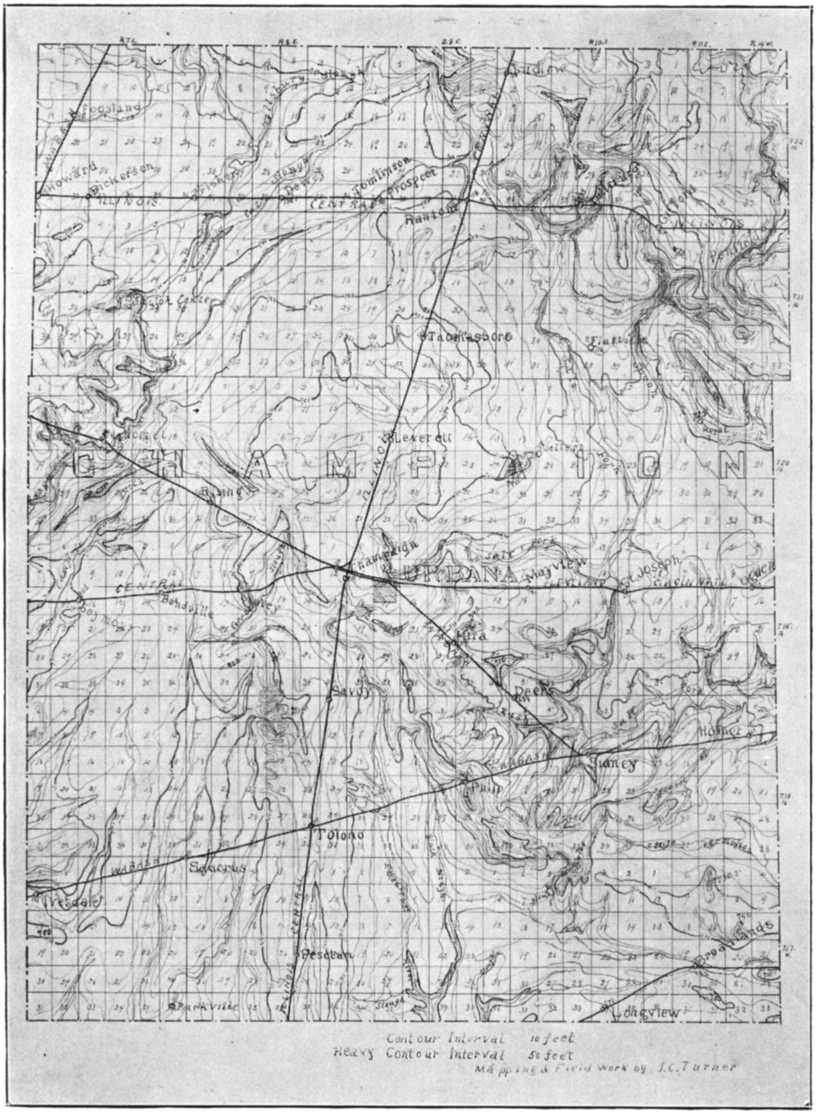
CONTOUR MAP OF CARROLL COUNTY, ILLINOIS.

wishes to use an aneroid for topographic purposes, to make himself thoroughly familiar with all their characteristics. Perhaps there is no better way to do this than to draw across a cyclonic area as delineated on the daily weather map, a line which shall be considered the trace of the observer's position as the area passes over him, and consider carefully the changes in the direction of wind, character of cloud, and barometric pressure that would occur. A series of such lines, some straight, others crooked, will bring out the cyclonic characters better than any amount of description could. For further information on this subject, see "Weather" by Abercrombie, Appleton's Science Series, "Elements of Meteorology" by Davis (Ginn and Company), and "A Popular Treatise on the Winds" by Ferrel, (Wiley and Sons). The last is not nearly so popular (elementary) as its title indicates, but is an excellent work.

From what has preceded, and an inspection of the barogram in Plate I, it is evident that the errors which may arise from changes in atmospheric pressure are very great, and that, if no measures are taken to correct them, the barometer would be entirely useless to the topographer, or even for hypsometry, but it is also evident that the errors so far considered may be corrected in either of two ways. The area to be surveyed may be divided into sections, each covering only a few square miles, and a self-registering barometer, carefully adjusted to read with that which is carried into the field, placed near the center of each section while it is being surveyed. The trace of this instrument will indicate the changes in pressure that have occurred, and furnish data for the correction of the readings taken in the field, provided the time at which each reading is taken is made part of the record. This method is open to the objection that the observer works mechanically and blindly, and is thus unable to apply the many little checks which he would otherwise find so useful, as well as to detect the larger errors, arising from surges, that will be spoken of further on. Another method is that by the use of gradients. Here the observer, before beginning work in the morning, carefully ascertains the barometric gradient, that

is the amount of rise or fall in a fixed interval, and corrects each reading as taken, by adding or subtracting the proper amount. In this way all errors due to pressure may be eliminated, so long as the gradient remains constant, but an inspection of Plate I, or of any barogram, will show that a gradient is not to be trusted for any great length of time. Sometimes it will run along for hours, or even days, with very little change; this is especially true in anticyclonic areas, and again several abrupt changes may occur within a few hours. On this account the observer must not only test his gradient by stopping at intervals to note the rate of change, but he must be continually on the alert for the signs which presage a change, such as variation in the character or amount of cloud, or the direction or velocity of the wind, etc. At first the recognition of those changes which mean a variation in gradient will be difficult, but a little practice will make it almost instinctive. This method has the advantage that it requires the wide-awake, intelligent judgment of the observer all the time he is in the field, and, when combined with careful descriptions and sketches made from all prominent points, yields very creditable results. If only one method for the correction of these errors can be used, this is decidedly the better, both for the reason indicated, and because there are times when the barometric variation is not the same over even so small an area as that indicated. It is desirable however, where possible, to combine the two, using the first only as a general check on the second.

In spite of all precautions, however, it will be found that there are times when the barometer is worse than useless. Such a time is indicated on Plate I, beginning at 9 in the morning of the 25th and ending shortly after noon on the 26th, another beginning at 3 in the afternoon of the 22d and ending at 4 in the morning of the 23d. Short disturbances of this kind occur also at 2 A.M. of the 21st, and shortly after noon of the 14th. These irregular movements almost always occur during storm periods accompanied by gusty winds, and are generally of short duration, though I have known them to extend over the greater part of a week.



CONTOUR MAP OF CHAMPAIGN COUNTY, ILLINOIS.

At such times the observer should proceed with great caution, or what is far better, cease work entirely.

An explanation of these irregularities may be found in the fact that cyclones and anticyclones are not the simple eddies that they are commonly supposed to be, but contain within them many smaller ones, each with the characteristics of the larger, but which pass over us so swiftly, or are so shallow, that they escape notice. It is these small eddies that give rise to the cumulus clouds and cirrus stripes of the anticyclone and to the cirrus stripes and clear spaces of the cyclone, while to the larger ones, or groups of them, we owe our thunder storms, and tornadoes. They are technically known as surges.

Having shown that by the exercise of the same intelligent attention which must accompany any scientific work, the sources of error which inhere in the aneroid may be kept under control, and that results sufficiently accurate for the purpose indicated may be reached, we come next to consider the method of procedure in the field.

Having assumed a datum plane, far enough below the surface at the starting point so that no negative readings need be recorded, we run a series of base lines crossing the area at intervals of five or ten miles, using every precaution to guard against errors, and establishing stations at frequent intervals, so well described that they may be recognized when again met with. These base lines should all be doubled, that is, each should be run in the opposite direction, readings being taken at the stations established during the first traverse. A comparison of the two sets of readings will usually enable the observer to eliminate all errors, if the work has been well done, but if wide differences are still found, a third traverse, more carefully made, should correct them. These base lines will furnish the means of establishing the water slopes of the streams that cross the area, and these, together with the base lines themselves, will enable the observer to frequently check his work while making the traverses with which the details are filled in.

No topographic survey can be absolutely correct, that is, the

results of the very best are only generalizations, taking account of the larger irregularities of surface, but paying no attention to the lesser ones, hence it is necessary that at the outstart a thorough understanding should be had as to the degree of accuracy desired, so that the traverses may be arranged to touch all points of elevation or depression that come within these limits. All points at which observations are made should of course be accurately located on the map. Much use should also be made of descriptions and sketches made on the spot.

Where railroads, or other lines of levels, cross the area, their profiles should be taken as base lines, but too much reliance should not be placed on their accuracy. Some of them are excellent and their results may be taken without question, but others are very poor. An error of one foot to the mile is not at all uncommon in these surveys, and much larger ones are frequently met with. One which I have in mind, the official profile of an Illinois road, has an error of nearly one hundred feet in about fifteen miles.

The results of all observations having been recorded in their proper places on the map, they should be translated into contour lines, which will at once indicate the variations in surface. See Plates II. and III. I would strongly advise that the preliminary contour map be made *by the observer*, and for each small section separately while the details of surface are fresh in his mind. These maps can then be brought together and re-drawn by more expert hands.

It was my fortune during the years 1892–3 to direct a survey of the entire state of Illinois, along the lines indicated above. The time allowed was so short that the work had to be pushed winter and summer, without regard to weather. The task was rendered much easier than it otherwise would have been, by the large number of railroad lines which cross the state in every direction, and by the kindly courtesy of their officials, through whom I was enabled to obtain profiles of the lines. These profiles, after they had been brought into accord, formed admirable base lines from which to carry on the other work. Under these conditions

the task was completed in sixteen months, with an average force of ten men, and at a total cost of twenty-five cents per square mile. The degree of accuracy attained can be inferred by the following facts. Each county was surveyed separately. As a rule the observers who surveyed contiguous counties were unacquainted with each other's results. When the county maps were brought together it was found that the average difference in the elevation assigned to common points was less than ten feet. A difference of twenty-five feet was occasionally met with, but was not frequent. These errors were corrected, and the maps re-drawn, omitting most of the elevations, but retaining the contours. Plate II. is a reproduction on a much reduced scale of the map of one of the rougher counties, while Plate III. represents one of the more level ones.

Better results could, of course, have been reached had it been possible to devote more time to the work.

C. W. ROLFE.

UNIVERSITY OF ILLINOIS,
December 20, 1894.